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MICROCLIMATES AND CORROSION: A MATHEMATICAL MODEL OF CORROSION FOR GANDO AFB, SPAIN

THESIS

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AFIT/GLM/LSM/90S-1

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The opinions and conclusions in this paper are those of the author and are not intended to represent the official position of the DOD, USAF, or any other government agency.

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FOR GANDO AFB, SPAIN

THESIS

Presented to the Faculty of the School of Systems and

and Logistics of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Logistics Management

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Lt Col, Spanish Air Force

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Preface

The purpose of this study was to improve the knowledge about local corrosion at Gando AFB, Spain, with the idea in mind of offering an useful tool to find out what areas inside the base were prone to be affected by corrosion and the relative degree (given in the form of an index) of coorosion to be encountered at every place; and knowing so, great step against environmental corrosion could be given.

One regression equation was modeled that tied together distance to the sea-shore and annual average wind existent at every location to develop the General Corrosion Index that is going to be encountered at that place.

Credit for any success in achieving this goal must, however, be shared with the many fine people who helped me throughout this effort.

I am indebted to my thesis advisor Dr. Brandt, and Lt Col Miller. They provided invaluable guidance, inspiration, and continual support.

I am grateful to all the people in Spain from whom I learned a great deal; however, a few deserve special recognition. Many thanks to Maj Martinez-Darve, Capt Orejas, and Sgt Pérez Trujillo. I am also deeply indebted to the people of The Spanish National Institute of Aerospace Technology (INTA), mainly to the Aeronautical Engineer Sr Sánchez Pascual, for this assistance in obtaining and

processing the samples' measurements used in this research effort.

Finally, I owe the greatest debt to my wife Maica, for her deep love and support, and to my children Javier, Susana, and Rocio, and also to my nephew Alfonso for their understanding and courage in living in a foreign environment "without" their father and uncle while he was devoted to this study.

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Abstract

The purpose of this thesis was to determine whether the degree of corrosion to be encountered at one specific location, due to the local weather conditions could be predicted by a mathematical model.

The corrosion data used were gathered by Spanish national Institute of Aerospace Technology at Gando AFB, Canary Island, Spain.

Only two variables, wind and distance to the sea shore of every location, were included in the model because they were found to be the only two varying from one place to another.

In doing so, one formula was devised using regression analysis that was statistically proved to be useful to predict the general corrosion index to be found at every place within a certain range at Gando AFB, Spain.

MICROCLIMATES AND CORROSION: A MATHEMATICAL MODEL OF CORROSION FOR GANDO AFB, SPAIN

I. Introduction

Background

Metal corrosion is a main concern of all air forces because it strongly damages airframes. Metal corrosion occurs at different rates at different air force bases. Aircraft stationed around the world are affected, in varying degrees, by metal corrosion that decreases these air forces' operational capability.

Although many works related to metal corrosion due to environmental factors have been completed, the corrosion phenomenon is still unclear since many variables influence the existence of metal corrosion. There are similar situations where corrosion acts at different rates on the same alloys. Each corrosion study needs to take into account the specific environmental factors that affect local corrosion.

Specific Problem

The specific problem faced here is to determine the influence of microclimates, if any, on metal corrosion. For the purpose of this study microclimate is defined as the existing climate at a specific geographical location. The study will focus on Gando AFB, Spain, where different

degrees of metal corrosion have been already experienced at different places along the base which are subject to the influence of different weather conditions.

If any influence is found it will permit the drawing a corrosion map of Gando; it will provide enough information to decide where to park aircraft safely, where to build future facilities, and what corrosion plan will need to be implemented to fight against local metal corrosion.

Investigative Questions

According to the problem stated above the following issues need to be addressed:

1. What are the factors affecting metal corrosion?

2. What information is already known about metal corrosion due to the above factors, and how can that information be used to avoid corrosion?

3. What are the findings of previous studies?

4. Can a mathematical model to predict Gando's corrosion be built?

5. Would that model be helpful in drawing a corrosion map of Gando?

II. Methodology

Introduction

This chapter presents a detailed explanation of the methodology used in this thesis.

The initial data (further explanations of it will be exposed along this study) have been already gathered from Gando AFB, where the Spanish National Institute of Aerospace Technology (INTA) has conducted several experiments regarding metal corrosion during recent years (15).

This thesis will process the data assuming that methods of measurement, that will be explained later, are correct.

During data processing the main purpose will be to determine what are the influencing variables (among the possible ones), and building a mathematical model using regression to see if a local corrosion map may be produced.

> Most general corrosive environmental factors can be used statistically in corrosion prediction precisely because they are beyond the control of local personnel; since they are directly measured from real physical changes, and they are not influenced by opinion (14:5).

The study will focus on Gando AFB, Spain. Gando is located at Gran Canaria Island, Canary Islands, Figure 1 is a map of the area. The air base is very close to the sea shore where a trade wind is almost permanently blowing. This characteristic seems to be a peculiar factor that need to be taken into account in any attempt to address Gando's corrosion.

Data Collection

The measurements of corrosion samples have been gathered by INTA and SAF during a field experiment done at Gando AFB (1983-1988). The meteorological factors have been provided for the National Meteorological Institute of Spain (NIM).

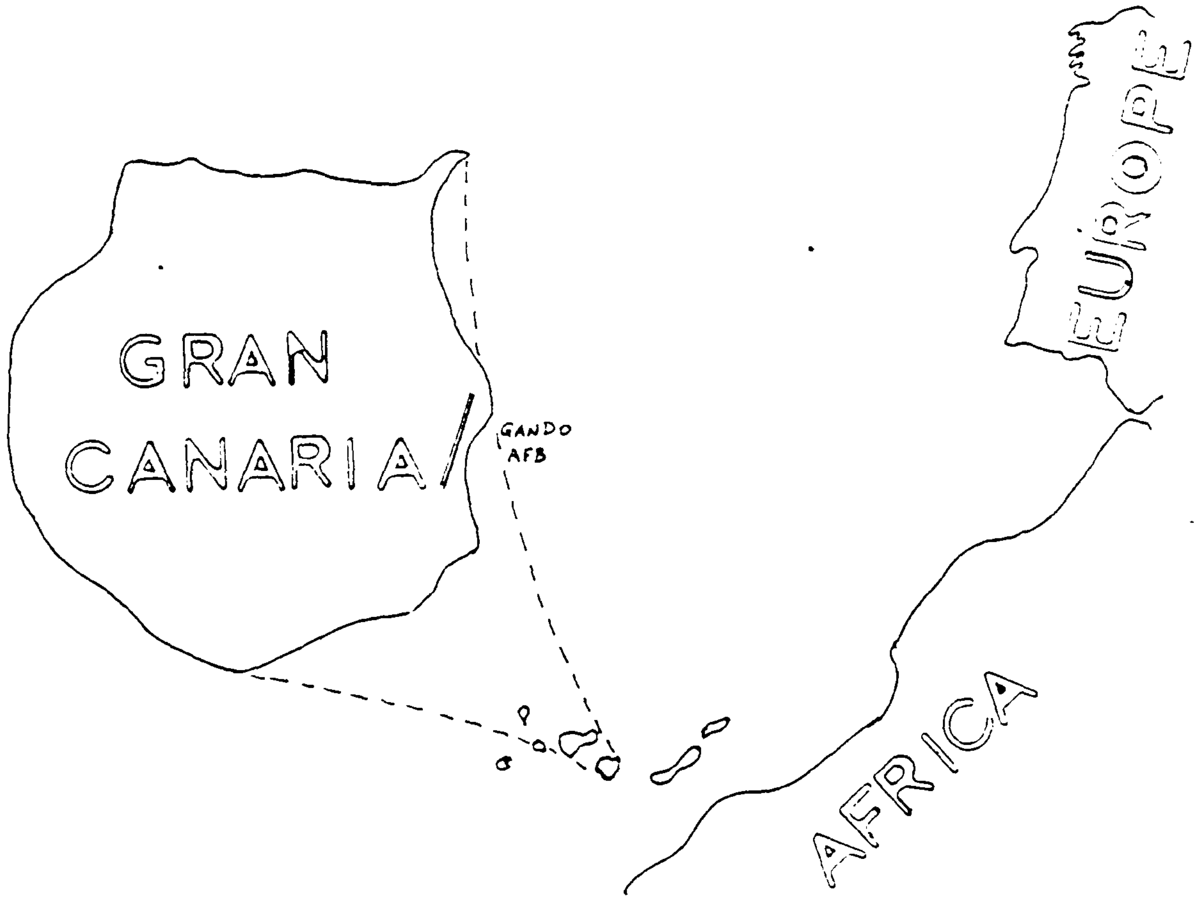


Figure 1. Gando's Geographical Location

Description of the Sample

Two samples each at 14 sites shown in Figure 2 were exposed to local weather during those five years.

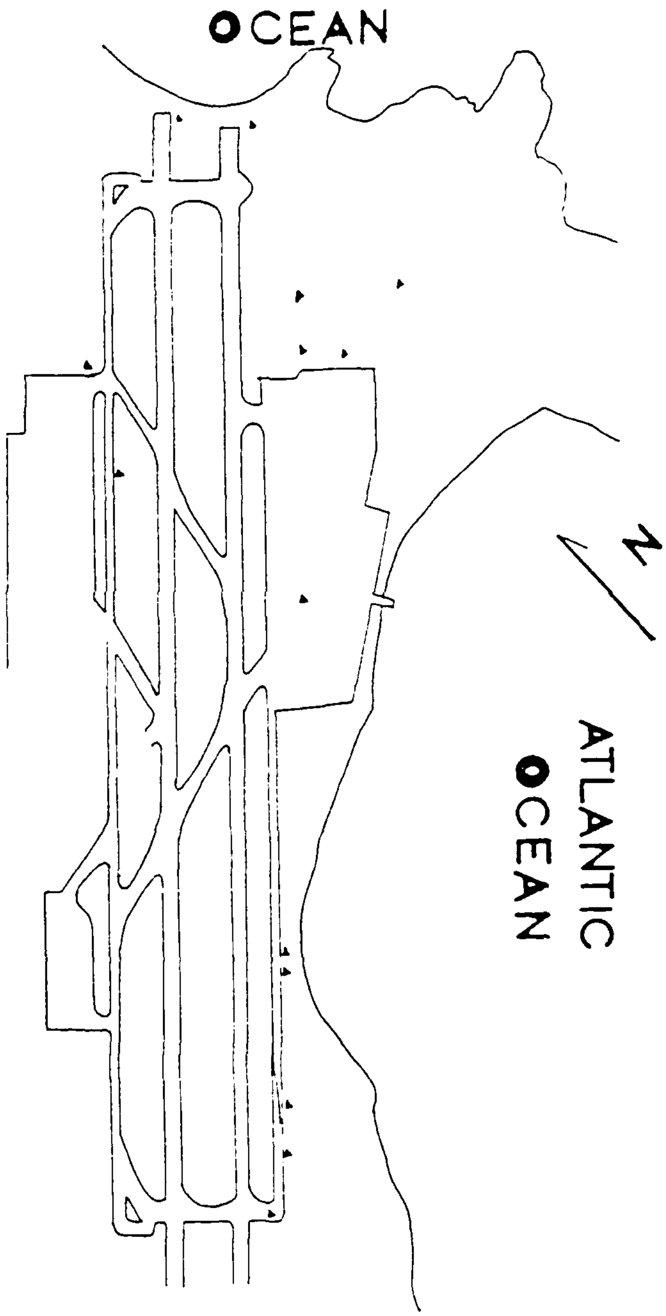


Figure 2: Local Display of Testing Sites

Measurements have been done every year to observe the variation in some characteristics. The samples were made from the same piece of metal (an alloy of Al-Cu-Mg, L-311, UNE L-311 38 11) to avoid chemical or mechanical differences if they were made from different metal batches. So, the experiment with identical initial conditions provided measurements for the change of the metal plates due only to the environmental factors. The measurements for both samples at each site, for every measured variable, were then averaged.

Physical Characteristics Measured and Methods Employed to Measure Them

Weight variation, elongation change, and observed corrosion (averaged microscopical measurements of maximum depth) have been measured for each probe at each site (15).

To measure the weight variation the initial weight was measured with an accuracy of five decimal points. The plates were removed from their sites at the end of each year and, after cleaning them (this was done brushing each sample under a water stream; sinking them later on during three minutes in a solution of nitric acid, density=1.33; rinsing them thoroughly with running water; degreasing them afterwards in an alcohol solution; and, finally, drying them with warm air), they were weighed with the same initial accuracy. The weight variation was obtained subtracting the later weight from the former one.

To measure the final mechanical characteristics, one probe for each plate was obtained always at one third the distance from the edge and in the same direction into the plate. INTA measurement's methods were applied to determine the final characteristics that have been averaged for both plates at each site.

To measure the depth of the corrosion found, several measurements have been done with a metalographic microscope on samples taken with two crossing cutting angles from the middle of each plate. The four measurements taken for each cut (two transverse and two longitudinal) have been averaged and combined in one only measurement as a percentage of the total inspected surface (15:42).

After the measurements explained above have been done, one Global Corrosion Index (GCI) has been established relating, in one figure, the loss of elongation index, the variation of weight index, and the maximum depth of corrosion index.

Regression: Basics Concepts (11)

Regression was chosen as the quantitative method for this study because of its ability to predict the value of one variable based on the values of other related variables. Regression analysis is a statistical tool which utilizes the relationship between two or more quantitative variables so that the dependent variable (y) can be predicted from the independent variables (x_1). Regression acts upon the basis

of setting the best fit between the dependent and independent variables.

For clarifying purposes a linear (a higher order can be generalized from the following reasoning) relationship can be taken into account between the response and the predictors variables. In doing so, one straight line (whose mathematical model is $y = \beta_0 + \beta_1 x$) is the graphical representation of that relationship. The modeler never can find with total accuracy what relationship exists between the variables, as it can be shown later in this research. The easiest step to approach modeling is the graphical one. The modeler can draw a scattergram of the sample data and, after that, he or she may try to fit one prediction line through the points guessing that the line is the representation of the population. "It is helpful to think of regression modeling as a five-step procedure:

Step 1: Hypothesize the deterministic component of the probabilistic model.

Step 2: Use sample data to estimate unknown parameters in the model.

Step 3: Specify the probability distribution of the random error term (ϵ), and estimate any unknown parameters of this distribution.

Step 4: Statistically check the usefulness of the model.

Step 5: When satisfied that the model is useful, use it for prediction, estimation, and other purposes (9:490)".

The best known method is the "least squares line", the "regression line", the "least squares prediction equation", or the "fitted line". This method offers the best fitting line that is found doing the SSE (sum of squares of the errors or "deviations", the vertical distances from the drawn points to the best predictor line) as small as possible. There are several formulas to calculate that regression line that can be found in specific texts (for instance, 9:494).

Regression: Generalization

The equation hypothesizes a probabilistic relation between the dependent and the independent variables.

The basic equation of the model is:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \epsilon$$

Where

y = the dependent variable, the one to be predicted.

β_0 = the y intercept.

β_i = the coefficients of the independent variables x_i.

ϵ = the random error component.

This model is called a probabilistic model, where ϵ stand for the random error phenomenon since no relation can be modeled that will exactly predict y from the independent variables. This can be easily understood since one natural phenomenon can be so complex that, even though the modeler

can research a large number of intervening variables, there always could be unknown ones that will not be included in the model. Besides, all natural phenomena have unexplained variations that cannot be exactly modeled. So, both sources of variation are included in the random error term, ϵ, of the probabilistic model. For practical purposes the model can be expressed only in terms of the deterministic portion of it. This can be done if four assumptions are taken into account:

"First: the mean of the probability distribution of ϵ is 0.

Second: the variance of the probability distribution of ϵ is constant for all the values of the independent variables, x.

Third: the probability distribution of ϵ is normal.

Fourth: the errors associated with any two different observations are independent (9:501)".

Regression: Technical and Statistical Aspects

The primary method to measure the contribution of x to predict y is to consider the sample multiple coefficient of determination R^2.

R^2 is an indicator of how well the prediction equation fits the data, and thereby represents a measure of the usefulness of the model. In other words, "it is another way to consider how much the errors of prediction of y were reduced by using the information provided by x" (9:517).

Statistical Tests

The statistical tests to support the thesis have been completed using the 1985 SAS Institute VMS version of SAS, Release 5.03. The sample data have been replicated in a SAS data file. Appendix A shows the employed data file.

The response, or dependent variable, will be identified as the GCI found at Gando AFB, and independent variables will be identified as those factors existing at fourteen different location along the base where the sites were posted. Here needs to be explained the reason why some of the data will not be taken into account and why other will be. After considering the existing literature on materials degradation and environmental factors, it can be concluded that there are no firm guidelines to setting working environmental corrosion standards (16:31). In addition, because this study is done only at one geographical place, Gando AFB, the corrosion study will focus only on those specific factors that, affecting corrosion, change from one site to another, instead of focusing on those generic environmental factors presented at the same level in all points of the AFB like sunshine, rainfall, etc. In doing so, the regression model will relate the GCI to those factors that really are different at each location. Since the only two variables that vary from one place to another according to the data provided by NIM, are wind and distance

to the sea shore, those will be the only two factors to be taken into account in building the regression model.

Furthermore, because the problem is to find out if one model can be built to be used to determine the corrosion index at every possible place inside the base, we will save from the original fourteen pair set of measurements one pair to check the usefulness of the model to be researched. The pair put apart is the ninth site (558 ft, 20 kts, GCI=71.0, see Appendix A).

Significance Tests

The following tests will be done to validate the new model that will be developed. The coefficient of determination will be analyzed. This coefficient measures the amount of variation that is explained by the regression line compared to the total variation. It can have a value between 0 and 1. The closer it is to one the better the regression line will fit through the data points (11).

The F-Test will also be used to interpret the overall statistical significance of the model. The larger the F computed value over the F table value means there is greater confidence that the model has statistical significance (11).

The t-Test will also be conducted. This test will measure the statistical significance of the independent variables individually. If the t calculated value exceeds the t table value, there will be greater confidence that the

independent variable is not equal to zero and therefore it will be included in the model (11).

Summary

This chapter began by introducing the environment surrounding the data. Next, a basic discussion of regression was presented. This presentation explained the generalized model set in this research effort and the assumptions done to choose the variables to be used in the specific model. The chapter also described the statistical tests used to verify the significance of the model.

III. Literature Review

When the human being left the Stone Age and began the Iron Age he faced a new and surprising problem. He could not believe that in a couple of years his iron arrow point had become corroded and broken. Nowadays, the composite and materials engineers are facing the same problem.

Corrosion is a pervasive problem in contemporary engineering systems. In effect, all engineering materials are subject to some form of environmental degradation (12:10). The problem is becoming more confusing since materials designed to reduce corrosion (composite materials) are creating a separate set of problems related to corrosion (4:66). Corrosion, the action, process, or effect of corroding (To corrode: to eat away, to wear away, gradually by chemical action) (20:253), has become a great problem that, at the present moment, has no exact definition nor permanent solution.

Even technical sources define corrosion in contrasting terms: "Corrosion is the deterioration of a substance (usually a metal) or its properties because of a reaction with its environment" (2:1-1) and "Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Deterioration by physical causes is not called corrosion, but is described as erosion, galling, or wear. Non-metals are not included in the

present definition" (19:1). For the purpose of this paper, corrosion is defined as the deterioration of a metal at different rates due to different environments.

The cost that the modern world has to pay due to corrosion is very large. It has been estimated at $20 billion per year in the U.S. (1:1). The cost in the USAF has been rounded to $1 billion per year (18:21).

Environmental factors have a capital importance on the corrosion phenomena:

> Metallic corrosion in the atmosphere is an electrochemical process which requires a film of water (not necessarily visible) on the metal surface. The appearance and disappearance of moisture will vary with a variety of climatic conditions (rain, humidity, wind, temperature, etc) as well as the presence of contaminants (atmospheric pollutant, oils, etc.) (17:6).

This literature review shows some of the problems related to corrosion:

1. Types of corrosion.
2. Where corrosion occurs at a major degree.
3. What factors are involved in corrosion.
4. What kind of metals are the most affected.
5. New prevention and corrosion control methods.

All of that will be researched in relation to the huge problem that Gando AFB, Spain is facing. The corrosion that occurs in that environment produces much concern, wastes money, and, above all, threatens its operational forces and installations. Corrosion can be described as the aircraft cancer (7:33).

1. Types of corrosion. Although there are many ways of classifying corrosion, the most common is to classify it by the appearance of the corroded metal: galvanic, or two metals corrosion (it is due to the electric current, caused by a galvanic cell, found in their coupled action); uniform attack or general overall corrosion (a form of deterioration that is distributed more or less uniformly over a surface); concentration-cell corrosion (galvanic corrosion localized only on certain points); pitting (highly localized corrosion resulting in deep penetration at only a few spots); parting (the selective attack of one or more components of an alloy); intergranular corrosion (corrosion that occurs preferentially at grain boundaries); stress corrosion (corrosion accelerated by stress); and erosion corrosion (deterioration of the surface due to the abrasive actions of moving particles and fluids) (1:23).

2. Where corrosion normally occurs. Most people are familiar with corrosion, but few understand the process that, step by step, destroys their properties. A natural question could be, "In what environment does corrosion occur?" The correct answer should be, "Just about any environment depending on what material we are concerned with" (2:1-3). Some other authors have described as many as forty ways for corrosion to occur; other authorities argue only two or three; and still others more safely say "Quite a few" (2:1-3).

The fact that corrosion occurs should not be cause for surprise. Almost all materials should be expected to deteriorate with time when exposed to the elements. "Corrosion is a perfectly natural process, as natural as water flowing downhill" (2:1-5).

Corrosion has been and continues to be a major problem behind material deterioration. Exposure to marine atmospheres, for instance, increases the rate of corrosion (16:47), but in the past many corrosion problem have been reduced through applications of simple paints.

Although there is no agreement regarding the definition of corrosion, some axioms regarding environments where corrosion occurs are accepted. Some environments are more corrosive than others. There are exceptions, but it is generally accepted as a fact that moist environment is more corrosive than dry air. Hot air is more corrosive than cold air. Hot water is more corrosive than cold water. Polluted air is more corrosive than clear air. Acids are more corrosive than bases. Salt water is more corrosive than fresh water. Stainless steel will outlast ordinary steel. No corrosion will occur in a vacuum, even at very high temperatures. It may be a surprise to some, but there are instances where every one of the above statements are incorrect, including the last one (2:1-7).

3. What factors are involved in corrosion. There is little or no controversy now about what factors cause forms

of corrosion. Current thinking in the case of ordinary corrosion is firmly grounded in electrochemical theory, and various formulas and equations have been devised which describe the chemical reactions which make-up most corrosion processes. In essence, electrochemical corrosion requires four primary factors: an anode, a cathode,an electrolyte, and an electronic circuit. Thus corrosion theorists are obliged to take into account considerations of the infinitely small and necessarily complex activities on the molecular and the ionic, electronic, and atomic levels. There are three basic kinds of corrosion: chemical, electrochemical, and physical, depending on the degree of the involvement of the ions, electrons, and atoms (2:1-10).

4. What kinds of metals are the most affected. The driving force that makes metals corrode is a natural consequence of their temporary existence in the metallic form. To reach this metallic state from their occurrence in nature in the form of various chemical compounds called ores, it is necessary for them to absorb and store up energy for later return by corrosion. The energy required and stored up varies from metal to metal. It is relatively high for such metals as magnesium, aluminum,and iron and relatively low for such metals as copper and silver (2:2-1). It can be said that the greater the stored energy, the greater is also the potential for corrosion; however, there is not a sure rule to assure what metal is going to corrode

due to that stored energy; corrosion engineers are inclined to prefer a "practical" table, instead of using the table of stored energies, to find out what metal is going to corrode in one specific environment (2:17-5).

5. New prevention and corrosion control methods. Even though corrosion exists, there are several actions that can be taken to control and decrease its effects. To fight against corrosion two tools are used: a) prevention and b) corrosion control programs.

a) Prevention. Fortunately, concern for corrosion is increasing. To fight against corrosion is a profitable business because it saves a great amount of money; concerns about prevention are flourishing everywhere. The newest published solutions to corrosion problems are summarized in seven operations:

Wash the aircraft, especially the area below the cabin floors to remove grime and dirt deposits than retain moisture; replace lubricants and corrosion inhibitors after each washing; maintain the aircraft finish to keep the corrosion inhibiting seal intact; maintenance of the seals between metal joints and the prompt replacement of sealant if it is damaged; drain point checks to ensure that they are free of clogging so water or other liquids can move through them; and application of corrosion inhibitor at regular intervals to areas of the aircraft where it can be removed by washing or abrasion (4:66).

Two factors already mentioned need more attention: inhibitors and protective coatings. Corrosion inhibitors are substances which sharply reduce corrosion when added to water, acid, or other liquid in small amounts (2:1-25). They are commonly added to acids, cooling waters, and steam, either continuously or intermittently to prevent serious corrosion (2:9-1); it can be found five categories of inhibitors: passivating, cathodic, organic, precipitate-inducing, and vapor phase (2:9-11). Protective coatings are protective barriers between materials and their environment and can be classified as inert, or essentially inert, and sacrificial (2:14-1). Various combination of these types are found in coating systems designed to use some or all of the several protective advantages provided. Furthermore, some uses of protective barriers while originally satisfactory, are now obsolete in the light of new discoveries. Nowadays, new paint, composed of epoxy and aliphatic polyurethane-finish systems, are ready to provide excellent protection for extended periods of time in adverse environments (13:83).

b) Corrosion control programs. The second big step to be taken into account in fighting against corrosion is the establishment of an effective corrosion control plan. This is not an easy task since all the problems concerning environment, types of alloys employed, what their usage will

be, and where the alloys are going to be used, are the foundations of the plan.

First of all, it is necessary to count on one useful system to determine the level of corrosion that is going to be found depending of the specific environment. Such a good tool is PACER LIME, an environmental corrosion severity classification system that takes into account all the environmental factors at a specific place (distance to the sea, rainfall, relative humidity, sulfur dioxide, solar radiation, and ozone), rates it in order to be aware of aircraft washing-rinsing intervals. A surprisingly large number of bases and weapons systems have cost benefit ratios-spent/saved money which would support the construction and use of rinse facilities (6:49). At Gando AFB, for instance, a large manpower base has been reduced due to the construction of an automatic washing rinsing facility (16:15), repainting to be done, and intervals among corrosion inspections. Summarizing, the system classifies the place according to its potential for corroding aircraft (16:2) and knowing so a big step against corrosion (controlling it) will be done.

Three specific algorithms are used in PACER LIME to process the preceding environmental factors, providing to the users with data on aircraft washings, complete repaints, and corrosion inspection/maintenance intervals. Those algorithms are deduced from the early study Rivet Bright

that provided an initial corrosion factor equation (that was severely questioned due to the fact that, in several cases, the guidelines provided by Rivet Bright correlated poorly with field experience and a few computational errors had occurred (18:3), combining certain weather and geographical factors, proposed by Air Force Logistics Command (AFLC) in 1971, with the intention of finding a correction factor applicable to all Air Force bases even though there is extreme difficulty in defining precisely the relation between corrosion and microclimate of sites very close one to another (17:14). The algorithms were developed by their authors with the idea not to provide a general rating system which would predict the corrosion damage to every metal (17:4), because the several factors which influence corrosion are present in a unique combination for a given site and to know them is not usually possible (18:4); rather they were going to offer the corrective intervals to be set and preventive measures to be designed at every Air Force base to fight against corrosion as a result of the severity of airbase environment. But PACER LIME is not the unique system that employs algorithms to classify the environment and its corrosivity:

> There has been considerable world-wide activity to develop models for evaluating environmental corrosivity. Such models are desired for predicting damage to specific materials or system, and for general damage predictions ranging from statistically based concepts to finely-detailed explicit formulas. Activities related to model development include (a) environmental correlation and regression type analysis of corrosion data, (b) an ever-

widening network of atmospheric contaminant measuring stations, and (c) the use of environmental chambers in efforts to develop realistic accelerated testing methods and to duplicate real-world corrosion damage in the laboratory (17:9).

There can be found at least 14 models relating corrosion test data and meteorological data, specially from eastern Europe (17:10).

It is also useful to point out here, to gain insight on the topic, the monumental work done at Spain by a young researcher about corrosion, cited as source number 14, where the possibility of predicting the behavior of metals exposed to the atmospheric environment is explained, and where several mathematical models, relating corrosion to environmental factors, are addressed (14:144).

At this point it would be useful to make some comments about a good tool for both preventing and controlling corrosion. Such a device is corrosion monitoring that has received much attention and interest in the last few years as evidenced by published papers, conferences, and case histories of successful application. There are considerable benefits to be obtained from a successful corrosion monitoring program: corrosion program may be designed, planned maintenance and inspection can be scheduled, improved reliability may be obtained, better use of materials may be achieved, and changes or abnormalities in the process (corrosion rate) can be detected. It is important to be aware of the limitations of corrosion

monitoring informations; they are only a quantitative guide to the actual behavior of process, and a confidence factor is established only through experience and particularly through comparison with other sources of information, for instance, nondestructive testing methods (3:41).

A successful corrosion control program must include attention to both the system and the personnel involved in setting it up and running it. The system needs to be reliable in its measurement; the obtained information, whenever it needs to be gathered, must be accurate and straightforward so that we can interpret the results; and it needs to be useful and easy to manage by middle level technicians:

> For personnel, experience is essential for success at any corrosion control plan. Success is only obtained when corrosion expertise is available, there is appreciation that the information is only a guidance, it is not axiomatic, and there is general recognition that corrosion control is valid and useful (3:42).

It must be pointed out that the role of communication in corrosion control is of capital importance. For example, during 1988, 168 meetings about corrosion were held worldwide (10:80):

> Effective communication is often the key to the realization of our goal of maximizing success at minimal cost, rather than the scientific, technological, and engineering aspects *per se*. None of our technical needs can be met, nor our technical recommendations implemented, unless we communicate in a timely and effective manner with the many resources, disciplines, and managerial levels involved in fighting against corrosion (5:88).

Summarizing, there are many published papers about corrosion. There is not a general agreement about what causes corrosion, but there is a universal consensus about the factors that need to be addressed in dealing with corrosion: environmental characteristics, atmospheric pollutants, corrosion inhibitors, protective coatings, and prevention and control programs.

The above statement already answers the first three investigative questions stated in chapter I: what are the factors affecting metal corrosion?, what information is already known about metal corrosion due to the above factors and how that information can be used to avoid corrosion?, and what are the findings of previous studies? The fourth and fifth questions inquire first, about the possibility of designing a mathematical model to predict Gando's corrosion; and second, if that model will permit the drawing of Gando's corrosion map. The following chapters are devoted to answer those questions.

IV. Analysis

Introduction

This chapter presents the way the model was developed and its subsequent analysis to check its usefulness. The procedure followed to do the above was the one already exposed containing five steps. Those five steps are the structural framework for this chapter.

Step 1: Hypothesize the deterministic component of the probabilistic model.

As it has been already stated in chapter II, only distance (d) and wind (w) are introduced in the deterministic model, in doing so the initial model is:

$$GCI = \beta_0 + \beta_1 d + \beta_2 w$$

Some attempts to hypothesize other different deterministic models were done (see Appendix D), but, after applying to all of them the steps that will be explained later for the chosen model, the author of this thesis chose the cited first order model with two quantitative independent variables, because it is the one that better accomplished all the steps.

Step 2: Use sample data to estimate unknown parameters in the model.

After running the SAS program shown in Appendix B, to find out the equation, throughout computerized regression

analysis, that relates one variable to others; the results for the unknown parameters are:

$$\beta_0 = 27.645785$$

$$\beta_1 = -0.007492$$

$$\beta_2 = 2.186433$$

According to the output shown in Appendix C, the deterministic model is:

$$GCI = 27.645785 - 0.007492\ d + 2.186433\ w$$

Step 3: Specify the probability distribution of the random error term ϵ, and estimate any unknown parameter of this distribution.

The first critical assumption of ϵ is the one concerning the mean of its probability distribution. As it can be seen on Appendix C, page 9, the mean of that frequency distribution is -1.640E-15 that can be considered almost zero.

The next result to be reviewed pertain to the second assumption of the random error ϵ (its variance is constant). As it can be seen on page 5, Appendix C, after plotting student residuals against the predicted values a random scattering of points is showing that the data meet the assumptions for equal variance. "If your data are well represented by your model then a plot of the residuals against the predicted values, should look like a random scattering of points" (SAS:315).

To prove the 'normality' of the frequency distribution of ϵ (the third assumption of the random error term), the SAS Proc Univariate was run on the residuals, showing the results on page 9 of Appendix C. It can be seen that W = .97, and PROB < W = .85. This indicates that the residuals are likely to be normally distributed (14:119). Furthermore, the Shapiro-Wilk Test for normality is conducted:

Ho: The residuals are normally distributed.

Ha: The residuals are not normally distributed.

Test statistic: W

Rejection Region: W < W (13, 0.05)

According to the table W (13, 0.05) = 0.866, and according to the output W = 0.97. Since 0.97 > 0.866, it can be concluded with a confidence factor of 90 percent that the residuals are normally distributed.

The remaining fourth assumption of ϵ (the errors associated with any two different observations are independent) will not be tested due to the small amount of existing observations, and being such the case the adequate Chi-Square Test to check for independence should be avoided (9:1028).

Step 4: statistically check the usefulness of the model.

For the following significance tests refer to the output shown on page 1, on Appendix C.

The sample multiple coefficient of determination, R^2 has a value of 0.9554 and this very high value implies that 95.54% of the sample variation in GCI is attributable to, or explained by (9:576), the independent variables (wind and distance).

To test the global usefulness of the model the F statistic 107.028 (provided by the mentioned output) will be compared with the F statistic provided by standard statistical tables with a confidence level of 95% (with 2 model degrees of freedom, numerator, and 10 error degrees of freedom, denominator) and doing so it was found that $F(.05,2,10) = 4.10$. The following test will formally test that global usefulness of the model:

Ho: $\beta_1 = \beta_2 = 0$

Ha: At least one of the parameters β and β is nonzero Test statistic: F

Rejection Region: $F > F(.05,2,10)$

Since it can be seen that $107.028 > 4.10$, Ho can be rejected, and one can conclude that at least one of the model coefficients β_1 and β_2 is nonzero.

Now that the model statistical significance has been proven, the statistical significance of the independent variables individually will be proven too; to do that the t-Test will be used. This test, if it is found that the absolute t value provided by the output is greater than the absolute t value provided by the standard statistical

tables, will be a proof that each individual independent variable should be included in the model. The test for the variable distance is:

H_o: $\beta_1 = 0$

H_a: $\beta_1 \neq 0$

Test statistic: t

Rejection Region: $| t | > | t(.025,10) |$

According to the table t(.025,10) = 2.228 and (according to the output) t = -4.038.

Because $|-4.038|>|2.228|$ it can be concluded that the independent variable distance should be included in the model.

The test for the variable wind is:

H_o: $\beta_2 = 0$

H_a: $\beta_2 \neq 0$

Test statistic: t

Rejection Region: $| t | > | t(.025,10) |$

According to the table t(.025,10) = 2.228 and(according to the output) t = 11.952.

Because $|11.952| > |2.228|$ it can be concluded that the independent variable wind should be included in the model.

Step 5: When satisfied that the model is useful, use it for prediction, estimation, and other purposes.

To check the usefulness of the model at this point it would be useful to remember that in the second chapter, page 11, a real pair of measurements was saved (distance=358 fts

and wind=20 kts) that produced a GCI of 71.0. Let us see what GCI is going to be predicted with our model:

$$GCI = 27.6457 - 0.0074\ d + 2.1664\ w\ ,$$

substituting the predicted GCI will be:

$$GCI = 66.8458$$

So, it can be seen that the model is useful for predicting the General Corrosion Index. Since, in that case, the predicted value is inside the range of ± 2 standard deviations of the real value. It needs to be stated here, to avoid further errors, that the model is useful for predicting GCI inside the range in which the sample data fall. To predict outside the range would be risky (9:538). Taking into account the foregoing, the model will allow one to draw a accurate Gando's corrosion map if the distance and wind measurements are inside the range of the sample data used to build the model; a prediction can be done outside that range, but the predictor needs to be aware that it will be a extrapolation and the findings will not be as accurate as those coming from inside the data range; even more, they can be risky.

Summary

This chapter is devoted to the task to build a regression model that allows the prediction of the GCI at Gando AFB, Spain. To do so, a general modeling procedure was followed and, after checking it for statistical usefulness, its usefulness for predicting GCI was also

tested. The conclusion that the model is useful was reached and a special warning was done advising that the model must be used into the range of the sample data to assure accurate results.

V. Conclusion

Even though the factors which influence corrosion are found in a unique combination, and their knowledge is not usually available and, in addition, the intimate relation between corrosion and microclimate of sites very close one to another is not easily defined; it can be stated here that the degree of the corrosion to be found at specific places in Gando AFB can be predicted. The only awareness to be taken into account is that the points whose GCIs are going to be predicted need to have its wind and distance values within the range of this study; furthermore, for the purpose of information and, being aware of the involved risk, GCI outside the foregoing range can be predicted. It is important to point out that the findings of this thesis were obtained using the data about corrosion gotten from an allow of Al-Cu-Mg and so any generalization for other materials must be avoided. Nevertheless, the regression equation researched on this study can be very useful to draw a corrosion map of Gando informing the managers where to park where they will less susceptible to corrosion aircraft, where to build future facilities, and, more important, what actions can be taken to decrease the GCI.

The following formula was devised:

$$GCI = 27.645785 - 0.007492\ d + 2.186433\ w$$

Any prevention plan to fight against corrosion at Gando AFB, needs to take into account those two variables. As greater the distance from the sea shore is, and as smaller the wind is, smaller the GCI will be.

Appendix A: Gando.dat SAS Data File (Including the Ninth Site)

92.2	131	30
82.0	164	28
70.9	1345	23
70.4	1312	25
66.5	1099	18
60.2	524	15
68.0	131	20
72.3	98	20
71.0	558	20
61.3	623	18
69.2	820	22
69.1	1935	26
71.0	1115	23
17.1	1902	4

Appendix B: SAS Regression Program

```
OPTIONS LS=79;
DATA CORROSI;
INFILE GANDO;
INPUT GCI DISTANCE WIND;
PROC REG DATA=CORROSI;
     MODEL GCI=DISTANCE WIND /CLI CLM R;
     OUTPUT OUT=PLAYA1 P=PREDICT R=RESIDUAL STUDENT=STRESS;
PROC PLOT DATA=CORROSI;
     PLOT GCI*DISTANCE='*';
     PLOT GCI*WIND='*';
PROC PLOT DATA=PLAYA1;
     PLOT STRESS*PREDICT='*';
     PLOT RESIDUAL*PREDICT='*';
     PLOT RESIDUAL*DISTANCE='*';
     PLOT RESIDUAL*WIND='*';
PROC UNIVARIATE DATA=PLAYA1 NORMAL PLOT;
     VAR RESIDUAL;
```

Appendix C: SAS Output

SAS 11:17 TUESDAY, APRIL 17, 1990 1

DEP VARIABLE: GCI

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	3353.42932	1676.71466	107.028	0.0001
ERROR	10	156.66145384	15.66614538		
C TOTAL	12	3510.09077			

ROOT MSE	3.958048	R-SQUARE	0.9554
DEP MEAN	66.93846	ADJ R-SQ	0.9464
C.V.	5.912966		

PARAMETER ESTIMATES

<table>
<tr><th>VARIABLE</th><th>DF</th><th>PARAMETER ESTIMATE</th><th>STANDARD ERROR</th><th>T FOR H0: PARAMETER=0</th><th>PROB > |T|</th></tr>
<tr><td>INTERCEP</td><td>1</td><td>27.64578526</td><td>4.73664526</td><td>5.837</td><td>0.0002</td></tr>
<tr><td>DISTANCE</td><td>1</td><td>-0.00749221</td><td>0.001855625</td><td>-4.038</td><td>0.0024</td></tr>
<tr><td>WIND</td><td>1</td><td>2.18643385</td><td>0.18293523</td><td>11.952</td><td>0.0001</td></tr>
</table>

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT
1	92.2000	92.2573	2.0782	87.6268	96.8879	82.2964	102.2182
2	82.0000	87.6372	1.8585	83.4963	91.7782	77.8943	97.3801
3	70.9000	67.8567	1.5423	64.4202	71.2933	58.3917	77.3218
4	70.4000	72.4769	1.6942	68.7018	76.2519	62.8837	82.0700
5	66.5000	58.7677	1.2370	56.0114	61.5240	49.5278	68.0075
6	60.2000	56.5164	1.7938	52.5196	60.5132	46.8338	66.1989
7	68.0000	70.3930	1.7948	66.3938	74.3922	60.7095	80.0765
8	72.3000	70.6402	1.8434	66.5329	74.7475	60.9115	80.3689
9	61.3000	62.3340	1.3574	59.3095	65.3584	53.0106	71.6573
10	69.2000	69.6037	1.1135	67.1227	72.0847	60.4422	78.7652
11	69.1000	69.9956	2.6932	63.9948	75.9964	59.3286	80.6627
12	71.0000	69.5800	1.2994	66.6847	72.4752	60.2977	78.8622
13	17.1000	22.1413	3.2535	14.8921	29.3906	10.7252	33.5575

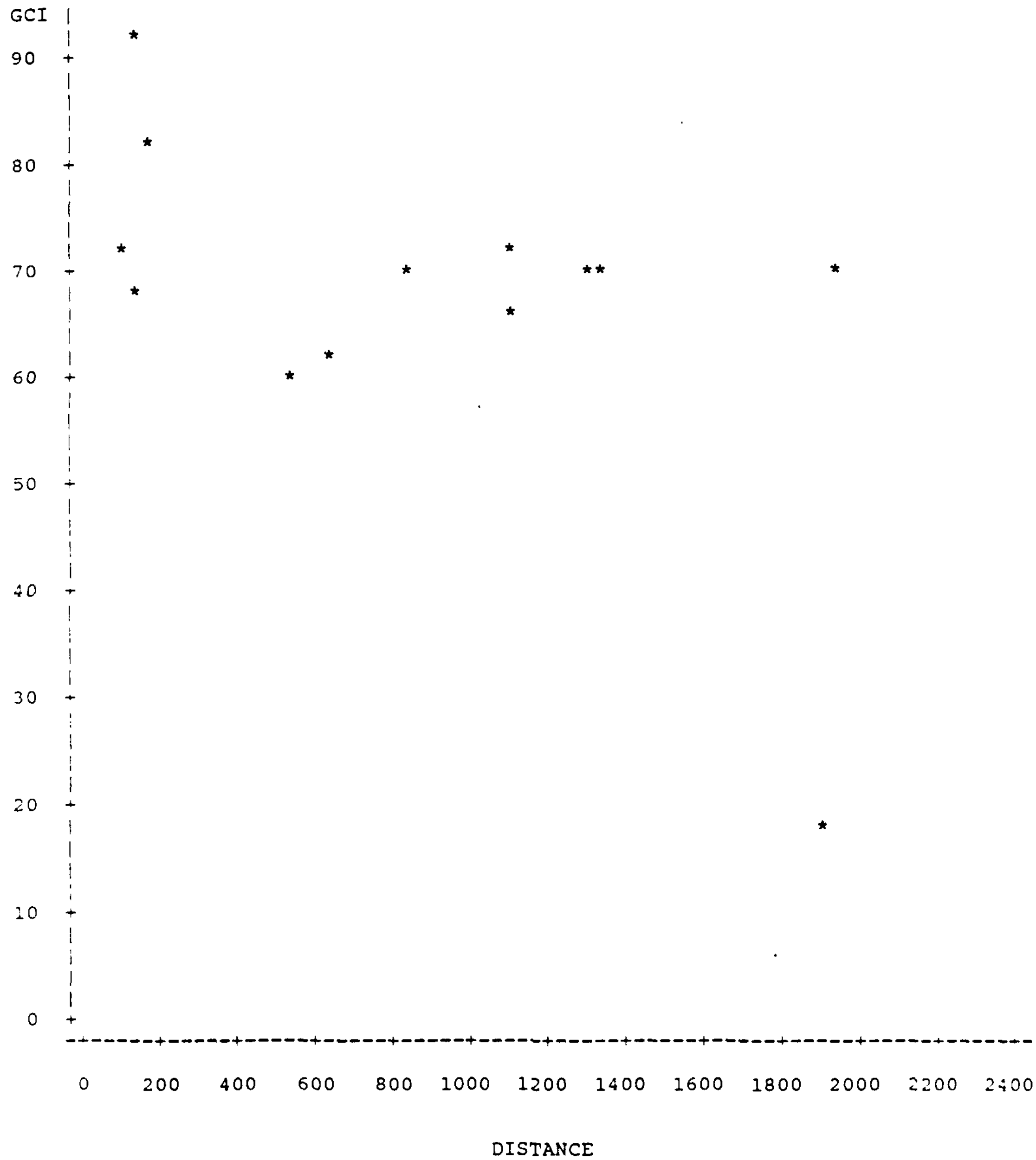
<table>
<tr><th>OBS</th><th>RESIDUAL</th><th>STD ERR RESIDUAL</th><th>STUDENT RESIDUAL</th><th>-2 -1 0 1 2</th><th>COOK'S D</th></tr>
<tr><td>1</td><td>-.057322</td><td>3.3686</td><td>-.017017</td><td>| | |</td><td>0.000</td></tr>
<tr><td>2</td><td>-5.6372</td><td>3.4946</td><td>-1.6131</td><td>| ***| |</td><td>0.245</td></tr>
<tr><td>3</td><td>3.0433</td><td>3.6452</td><td>0.8349</td><td>| |* |</td><td>0.042</td></tr>
<tr><td>4</td><td>-2.0769</td><td>3.5771</td><td>-.580597</td><td>| *| |</td><td>0.025</td></tr>
<tr><td>5</td><td>7.7323</td><td>3.7598</td><td>2.0566</td><td>| |****|</td><td>0.153</td></tr>
</table>

```
                    STD ERR    STUDENT                      COOK'S
OBS    RESIDUAL    RESIDUAL   RESIDUAL   -2 -1  0  1  2         D

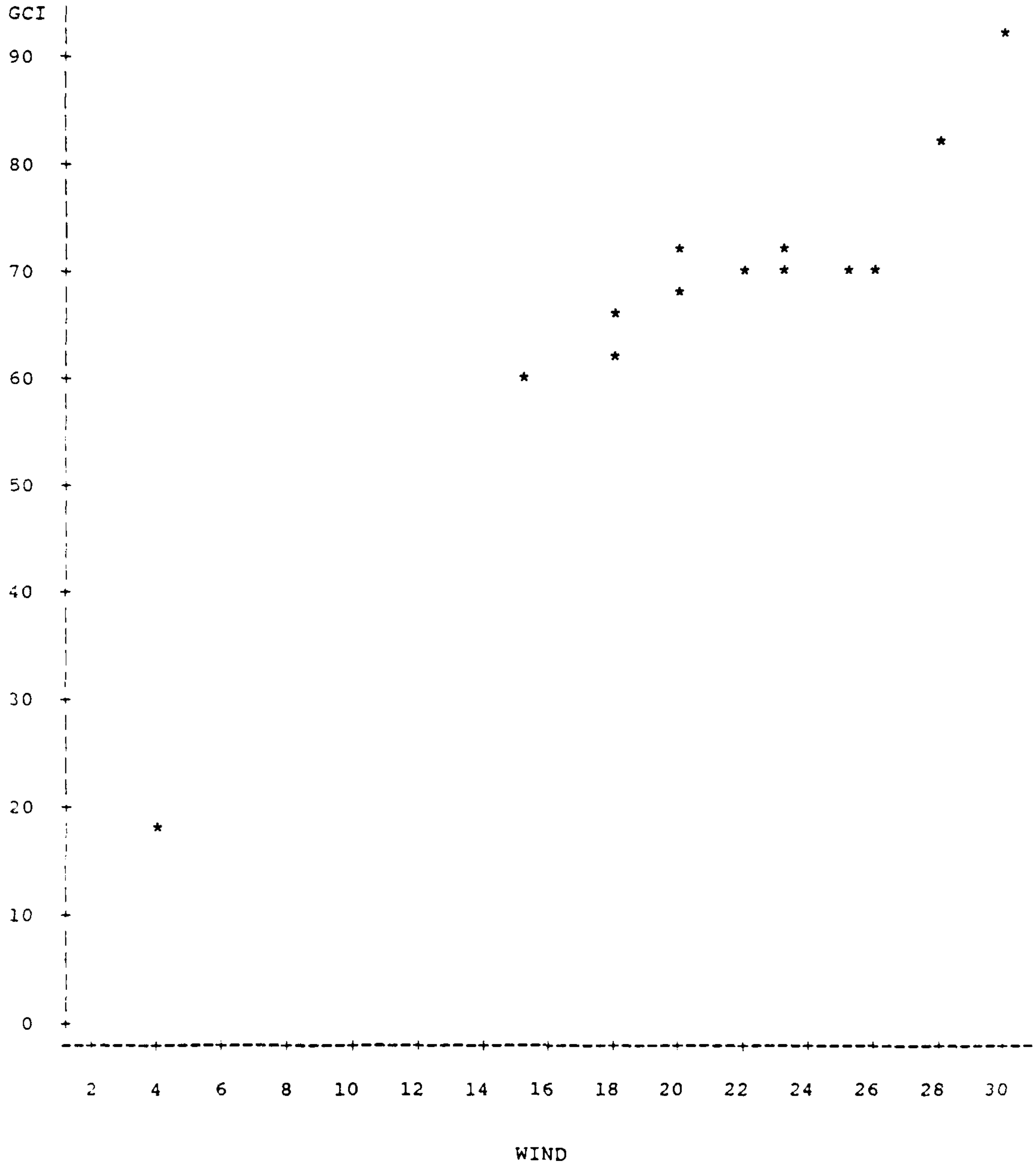
    6    3.6836      3.5282     1.0440   |      |**    |     0.094
    7    -2.393      3.5277   -0.67834   |     *|      |     0.040
    8    1.6598      3.5026     0.4739   |      |      |     0.021
    9    -1.034      3.7180   -.278092   |      |      |     0.003
   10  -.403721      3.7982   -.106293   |      |      |     0.000
   11  -.895647      2.9005   -.308789   |      |      |     0.027
   12    1.4200      3.7387     0.3798   |      |      |     0.006
   13   -5.0413      2.2541    -2.2365   |  ****|      |     3.473

SUM OF RESIDUALS            -2.13163E-14
SUM OF SQUARED RESIDUALS        156.6615
PREDICTED RESID SS (PRESS)      428.6182
```

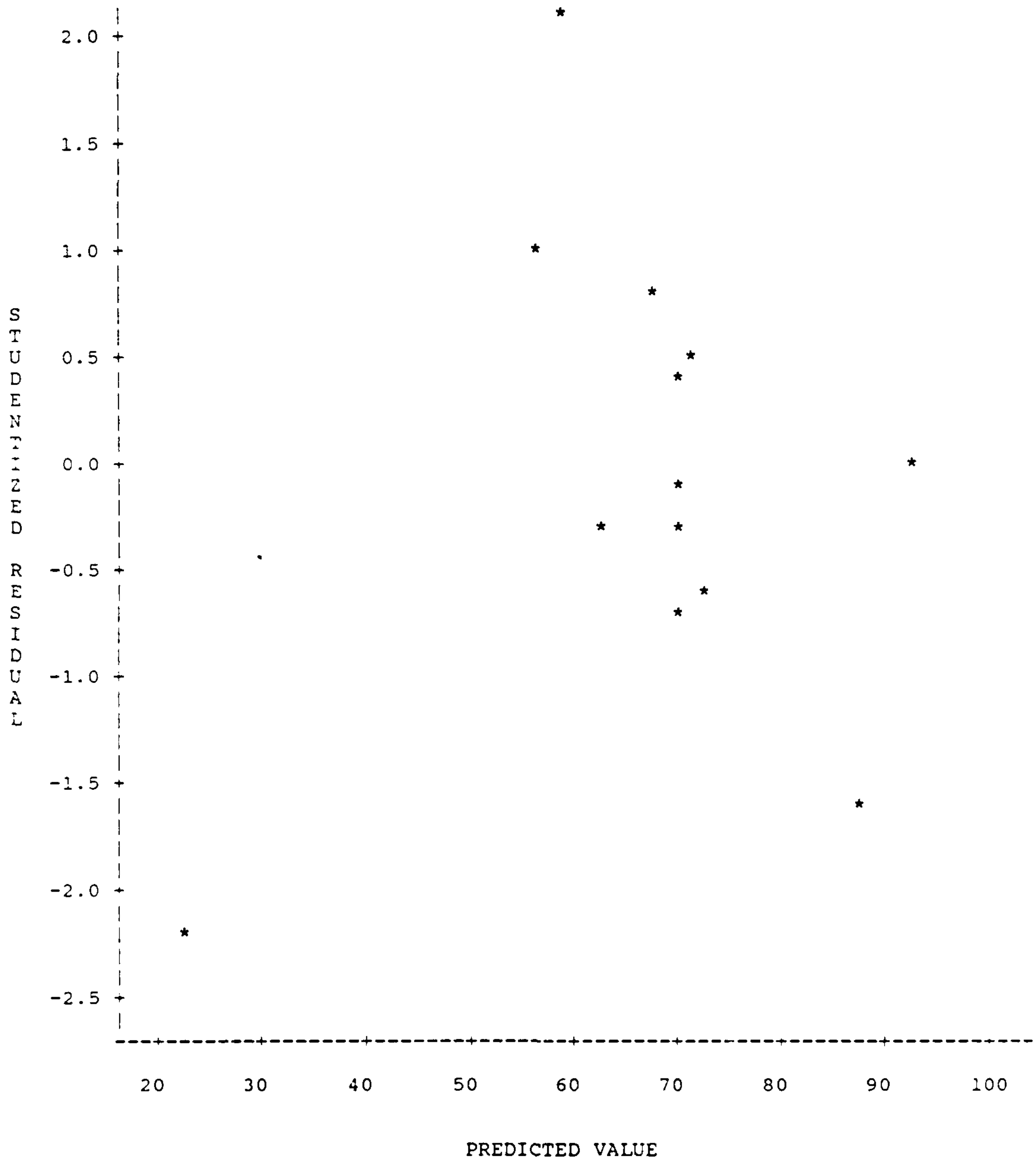
PLOT OF GCI*DISTANCE SYMBOL USED IS *



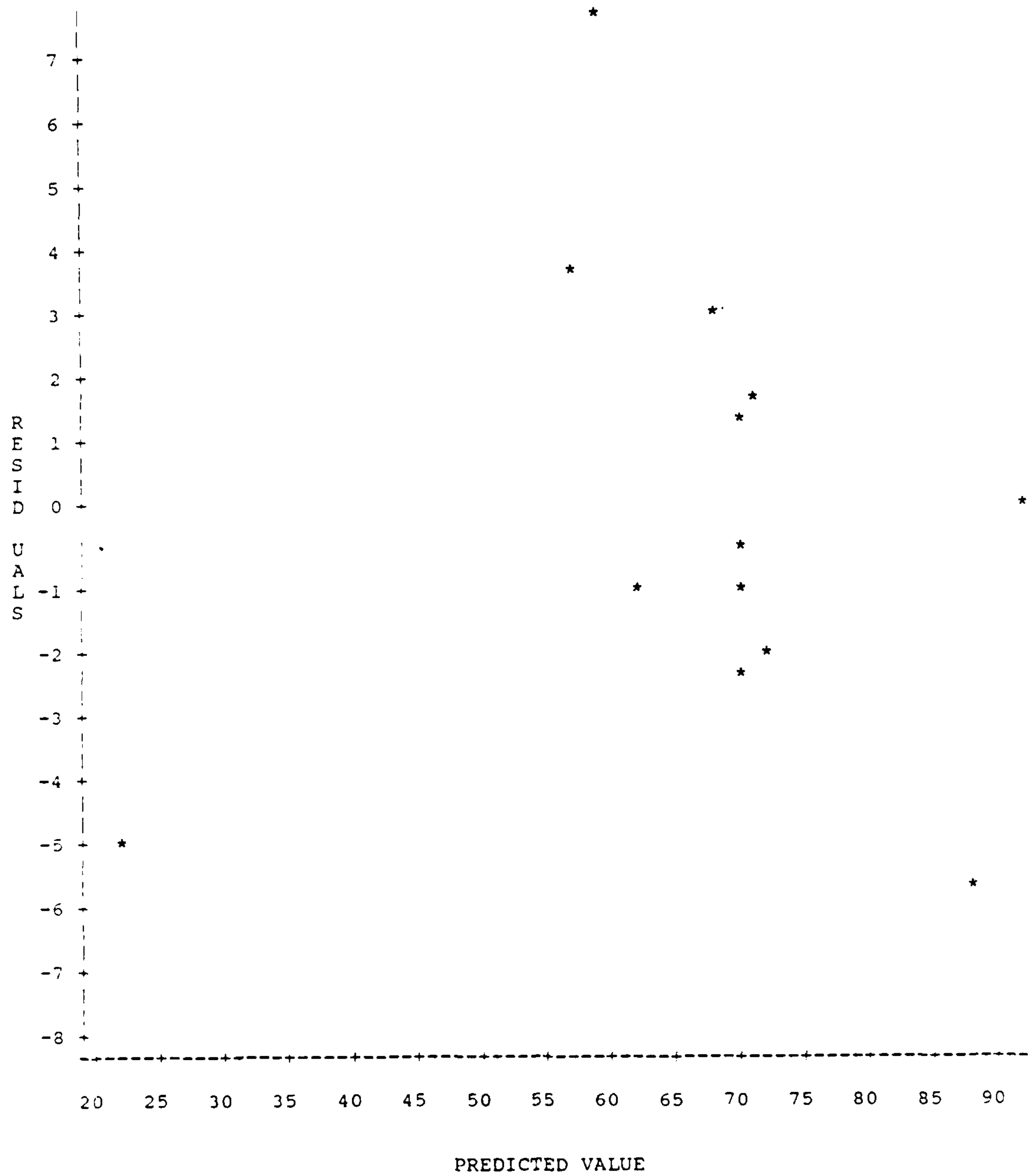
PLOT OF GCI*WIND SYMBOL USED IS *



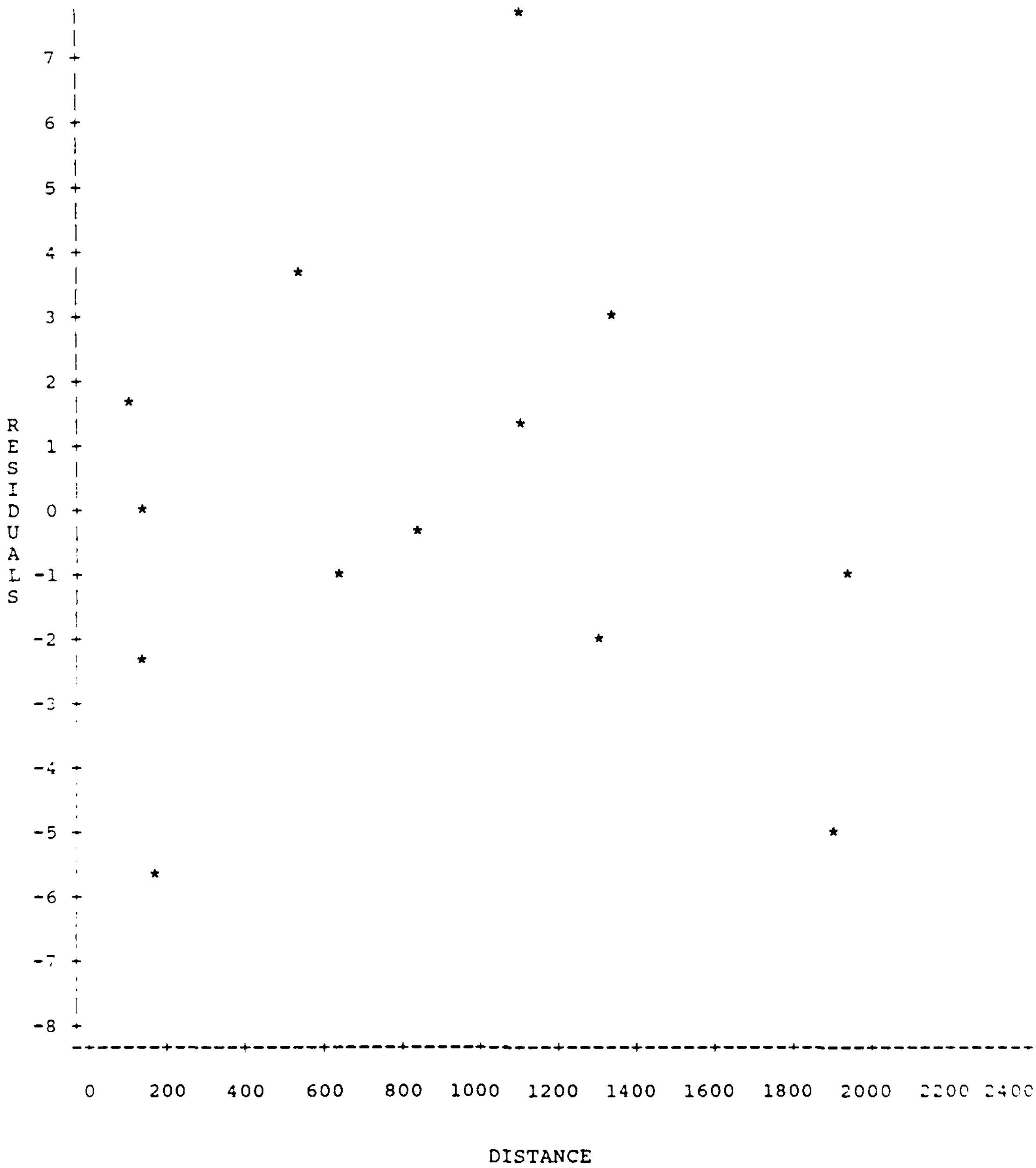
PLOT OF STRESS*PREDICT SYMBOL USED IS *



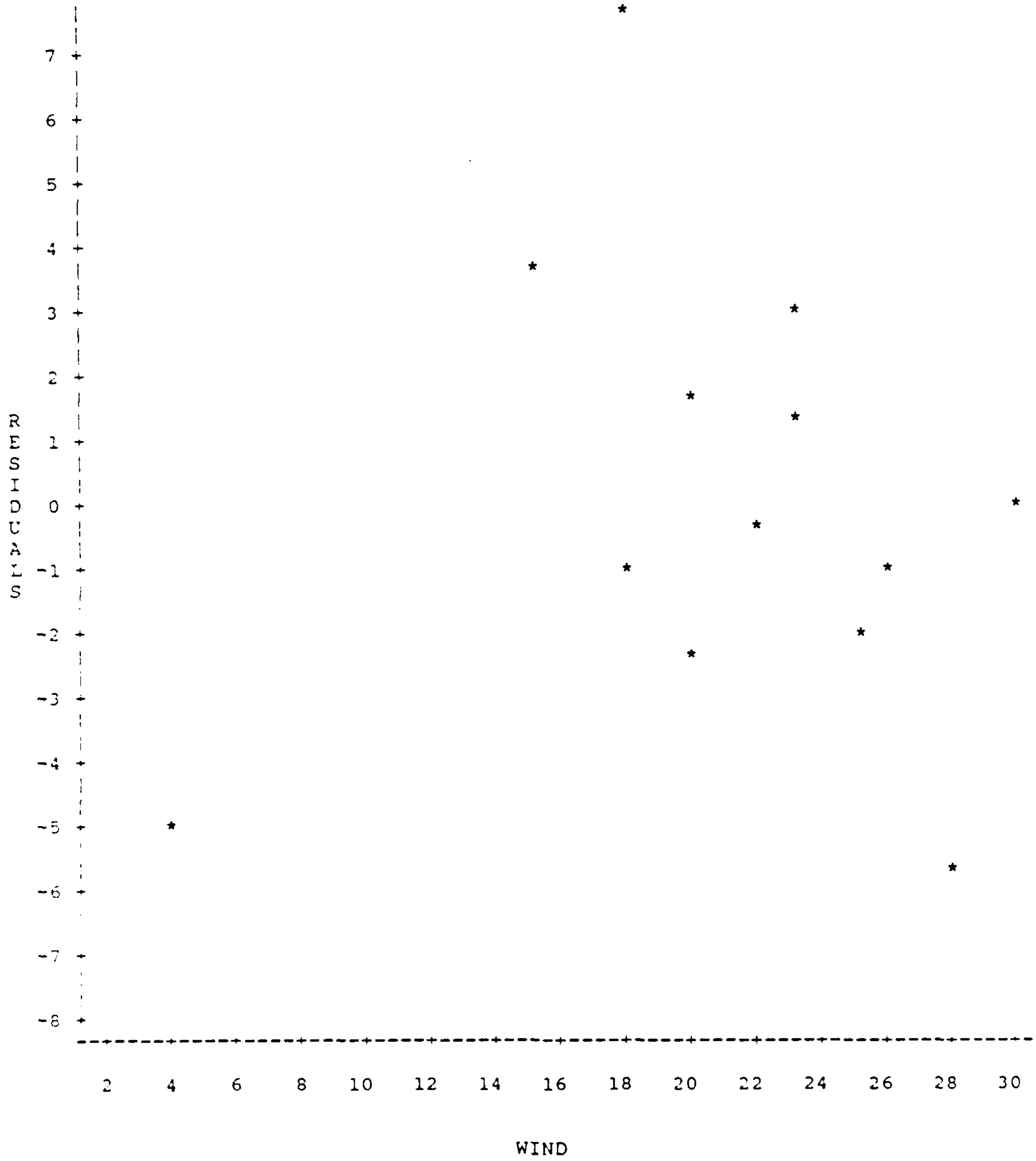
PLOT OF RESIDUAL*PREDICT SYMBOL USED IS *



PLOT OF RESIDUAL*DISTANCE SYMBOL USED IS *



PLOT OF RESIDUAL*WIND SYMBOL USED IS *



```
                                UNIVARIATE

VARIABLE=RESIDUAL          RESIDUALS

                                  MOMENTS

                  N                  13  SUM WGTS             13
                  MEAN       -1.640E-15  SUM          -2.132E-14
                  STD DEV       3.61319  VARIANCE        13.0551
                  SKEWNESS     0.451174  KURTOSIS         0.5749
                  USS           156.661  CSS             156.661
                  CV             -99999  STD MEAN        1.00212
                  T:MEAN=0   -1.636E-15  PROB>|T|              1
                  SGN RANK         -2.5  PROB>|S|       0.888841
                  NUM ^= 0           13
                  W:NORMAL     0.970388  PROB<W             0.85

             QUANTILES(DEF=4)                                    EXTREMES

100% MAX     7.73234      99%       7.73234                 LOWEST     HIGHEST
 75% Q3      2.35151      95%       7.73234                -5.6372     1.42005
 50% MED   -0.403721      90%       6.11285                -5.0413     1.65977
 25% Q1      -2.2349      10%       -5.3989                 -2.393     3.04325
  0% MIN     -5.6372       5%       -5.6372                -2.0769     3.68362
                           1%       -5.6372                 -1.034     7.73234

RANGE        13.3696
Q3-Q1        4.58643
MODE         -5.6372

STEM LEAF                    #                                     BOXPLOT
   0 8                       1                                        |
   0 1234                    4                                     +-----+
  -0 221100                  6                                     *-----*
  -0 65                      2                                        |
     ----+----+----+----+
MULTIPLY STEM.LEAF BY 10**+01

                          NORMAL PROBABILITY PLOT
          7.5+                                       +++*+++++++
             |                              +++++*+*+*+++++*+
             |                     ++++++*+*+*+*+*+* *
         -7.5+++++++++++*+++ *
              +----+----+----+----+----+----+----+----+----+----+
                  -2        -1         0        +1        +2
```

Appendix D: SAS Programs and Output for Other Researched Models

```
OPTIONS LS=79;
DATA CORROSI;
INFILE GANDO;
INPUT GCI DISTANCE WIND;
WINDIST=WIND*DISTANCE;
PROC REG DATA=CORROSI;
     MODEL GCI=DISTANCE WIND WINDIST / CLI CLM R;
     OUTPUT OUT=PLAYA3 P=PREDICT R=RESIDUAL STUDENT=STRESS;
PROC PLOT DATA=PLAYA3 ;
     PLOT STRESS*PREDICT='*';
     PLOT RESIDUAL*PREDICT='*';
PROC UNIVARIATE DATA=PLAYA3 NORMAL;
     VAR RESIDUAL;

OPTIONS LS=79;
DATA CORROSI;
INFILE GANDO;
INPUT GCI DISTANCE WIND;
LOGGCI=LOG(GCI);
PROC REG DATA=CORROSI;
     MODEL LOGGCI=DISTANCE WIND / CLI CLM R;
     OUTPUT OUT=PLAYA2 P=PREDICT R=RESIDUAL STUDENT=STRESS;
PROC PLOT DATA=PLAYA2;
PLOT STRESS*PREDICT='*';
PROC UNIVARIATE DATA=PLAYA2 NORMAL;
     VAR RESIDUAL;

OPTIONS LS=79;
DATA CORROSI;
INFILE GANDO;
INPUT GCI DISTANCE WIND;
WINDCUB=WIND*WIND*WIND;
PROC REG DATA=CORROSI;
     MODEL GCI=DISTANCE WIND WINDCUB / CLI CLM R;
     OUTPUT OUT=PLAYACUB P=PREDICT R=RESIDUAL STUDENT=STRESS;
PROC PLOT DATA=PLAYACUB;
     PLOT STRESS*PREDICT='*';
     PLOT RESIDUAL*PREDICT='*';
PROC UNIVARIATE DATA=PLAYACUB NORMAL;
     VAR RESIDUAL;
```

DEP VARIABLE: GCI

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	3396.54495	1132.18165	89.740	0.0001
ERROR	9	113.54581478	12.61620164		
C TOTAL	12	3510.09077			

ROOT MSE	3.551929	R-SQUARE	0.9677
DEP MEAN	66.93846	ADJ R-SQ	0.9569
C.V.	5.306261		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	38.83619572	7.39665350	5.251	0.0005
DISTANCE	1	-0.0157002	0.004741994	-3.311	0.0091
WIND	1	1.68454606	0.31726467	5.310	0.0005
WINDIST	1	0.0003817792	0.0002065186	1.849	0.0976

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT
1	92.2000	88.8162	2.6349	82.8555	94.7770	78.8116	98.8209
2	82.0000	85.1818	2.1321	80.3587	90.0049	75.8103	94.5533
3	70.9000	68.2744	1.4024	65.1019	71.4468	59.6357	76.9131
4	70.4000	72.8736	1.5355	69.4001	76.3471	64.1198	81.6273
5	66.5000	59.4559	1.1709	56.8072	62.1046	50.9955	67.9163
6	60.2000	58.8783	2.0551	54.2292	63.5274	49.5951	68.1614
7	68.0000	71.4707	1.7129	67.5957	75.3456	62.5500	80.3913
8	72.3000	71.7368	1.7574	67.7613	75.7123	62.7720	80.7016
9	61.3000	63.6581	1.4131	60.4614	66.8548	55.0105	72.3057
10	69.2000	69.9094	1.0128	67.6182	72.2005	61.5540	78.2647
11	69.1000	71.4619	2.5437	65.7077	77.2161	61.5789	81.3449
12	71.0000	69.8658	1.1763	67.2049	72.5267	61.4016	78.3300
13	17.1000	18.6172	3.4869	10.7293	26.5052	7.3575	29.8770

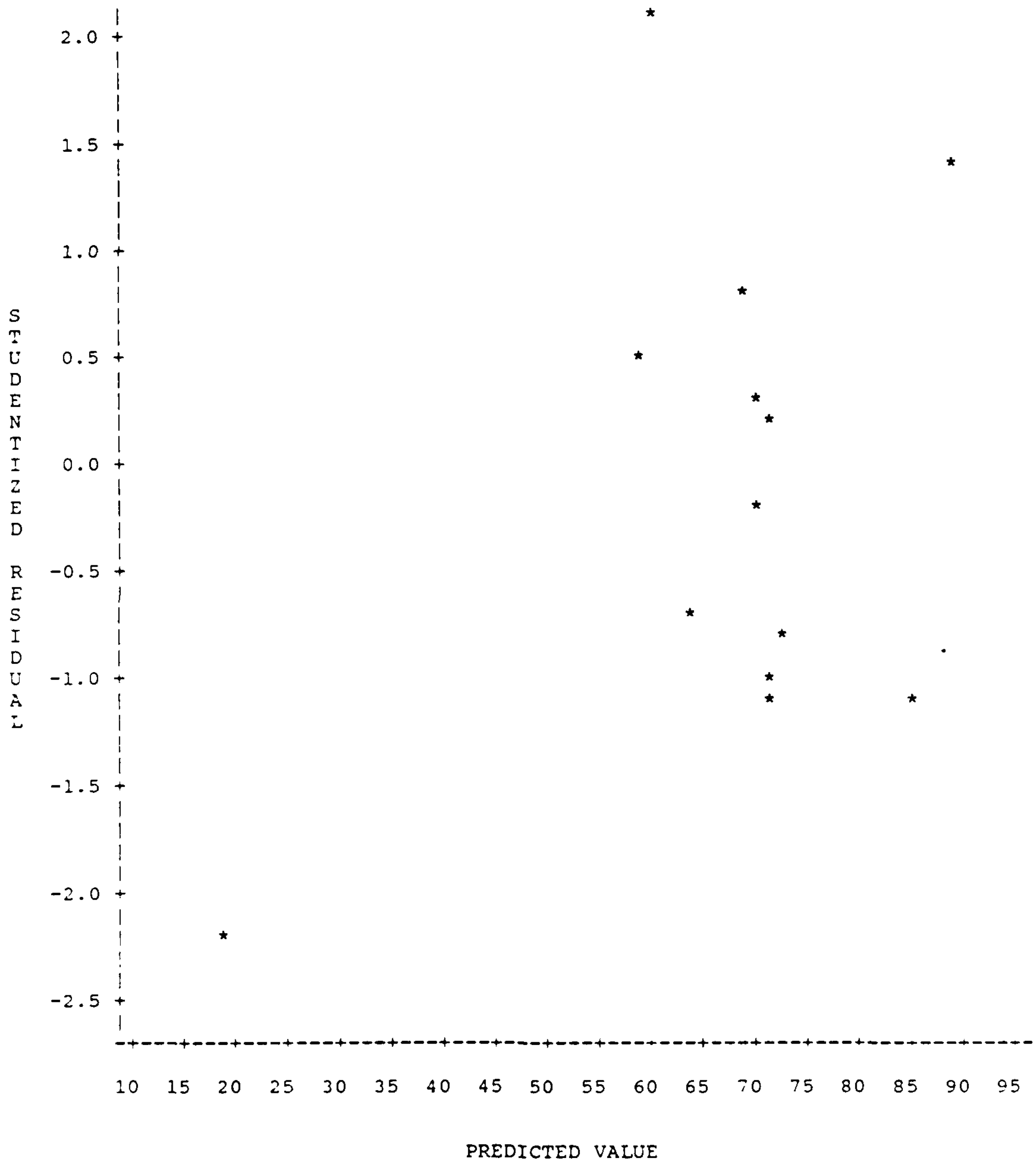
OBS	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
1	3.3838	2.3819	1.4206	| |** |	0.617
2	-3.1818	2.8409	-1.12	| **| |	0.177
3	2.6256	3.2634	0.8046	| |* |	0.030
4	-2.4736	3.2029	-.772298	| *| |	0.034

```
                          STD ERR     STUDENT                            COOK'S
OBS         RESIDUAL     RESIDUAL    RESIDUAL    -2 -1  0  1  2               D

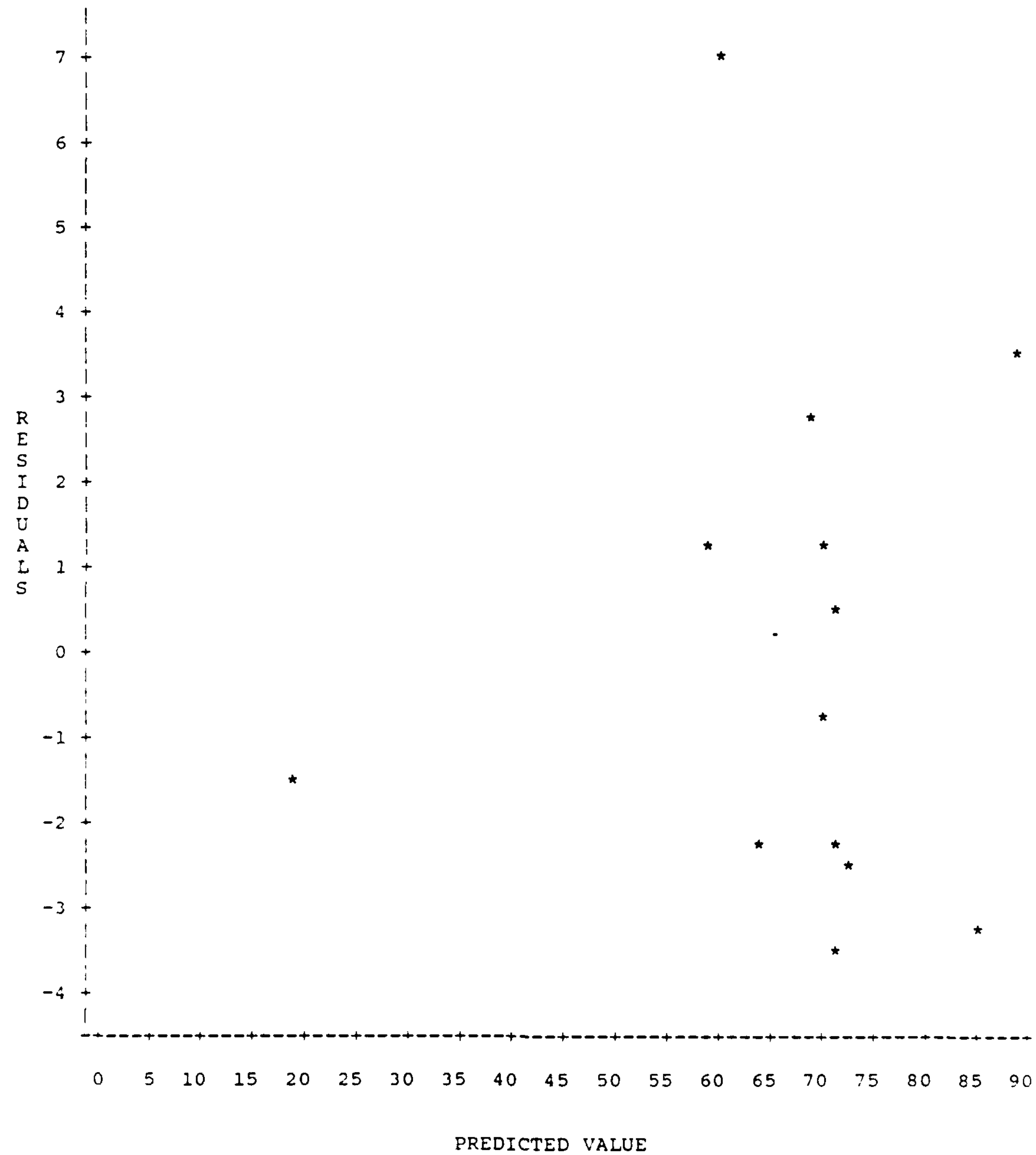
      5       7.0441       3.3534      2.1006    |       |****   |        0.134
      6       1.3217       2.8970      0.4562    |       |       |        0.026
      7      -3.4707       3.1116     -1.1154    |     **|       |        0.094
      8       0.5632       3.0867      0.1825    |       |       |        0.003
      9      -2.3581       3.2587     -.723622   |      *|       |        0.025
     10      -.709369      3.4045     -.208364   |       |       |        0.001
     11      -2.3619       2.4791     -.952711   |      *|       |        0.239
     12       1.1342       3.3515      0.3384    |       |       |        0.004
     13      -1.5172       0.6766     -2.2424    |   ****|       |       33.384

SUM OF RESIDUALS              -2.44249E-14
SUM OF SQUARED RESIDUALS          113.5458
PREDICTED RESID SS (PRESS)        1969.436
```

PLOT OF STRESS*PREDICT SYMBOL USED IS *



PLOT OF RESIDUAL*PREDICT SYMBOL USED IS *



UNIVARIATE

VARIABLE=RESIDUAL RESIDUALS

MOMENTS

N	13	SUM WGTS	13
MEAN	-1.879E-15	SUM	-2.442E-14
STD DEV	3.07606	VARIANCE	9.46215
SKEWNESS	0.984723	KURTOSIS	0.689811
USS	113.546	CSS	113.546
CV	-99999	STD MEAN	0.853146
T:MEAN=0	-2.202E-15	PROB>|T|	1
SGN RANK	-4.5	PROB>|S|	0.779828
NUM ^= 0	13		
W:NORMAL	0.911359	PROB<W	0.26

QUANTILES(DEF=4)

100% MAX	7.0441	99%	7.0441
75% Q3	1.97367	95%	7.0441
50% MED	-0.709369	90%	5.57996
25% Q1	-2.4177	10%	-3.3551
0% MIN	-3.4707	5%	-3.4707
		1%	-3.4707
RANGE	10.5148		
Q3-Q1	4.39141		
MODE	-3.4707		

EXTREMES

LOWEST	HIGHEST
-3.4707	1.1342
-3.1818	1.32172
-2.4736	2.62563
-2.3619	3.38375
-2.3581	7.0441

DEP VARIABLE: LOGGCI

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	2	1.72330072	0.86165036	30.790	0.0001
ERROR	10	0.27984538	0.02798454		
C TOTAL	12	2.00314610			

ROOT MSE	0.1672858	R-SQUARE	0.8603
DEP MEAN	4.148573	ADJ R-SQ	0.8324
C.V.	4.03237		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	3.25897038	0.20019298	16.279	0.0001
DISTANCE	1	-0.000170381	.00007842746	-2.172	0.0549
WIND	1	0.0495328	0.007731706	6.406	0.0001

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT
1	4.5240	4.7226	.0878349	4.5269	4.9183	4.3016	5.1436
2	4.4067	4.6179	.0785476	4.4429	4.7930	4.2062	5.0297
3	4.2613	4.1691	.0651864	4.0238	4.3143	3.7690	4.5691
4	4.2542	4.2738	.0716066	4.1142	4.4333	3.8683	4.6792
5	4.1972	3.9633	0.052283	3.8468	4.0798	3.5728	4.3538
6	4.0977	3.9127	.0758135	3.7438	4.0816	3.5035	4.3219
7	4.2195	4.2273	.0758585	4.0583	4.3963	3.8180	4.6366
8	4.2808	4.2329	.0779095	4.0593	4.4065	3.8217	4.6441
9	4.1158	4.0444	.0573694	3.9166	4.1722	3.6504	4.4385
10	4.2370	4.2090	.0470611	4.1041	4.3138	3.8218	4.5962
11	4.2356	4.2171	0.1138	3.9635	4.4708	3.7663	4.6680
12	4.2627	4.2083	.0549178	4.0859	4.3306	3.8159	4.6006
13	2.8391	3.1330	0.1375	2.8267	3.4394	2.6505	3.6155

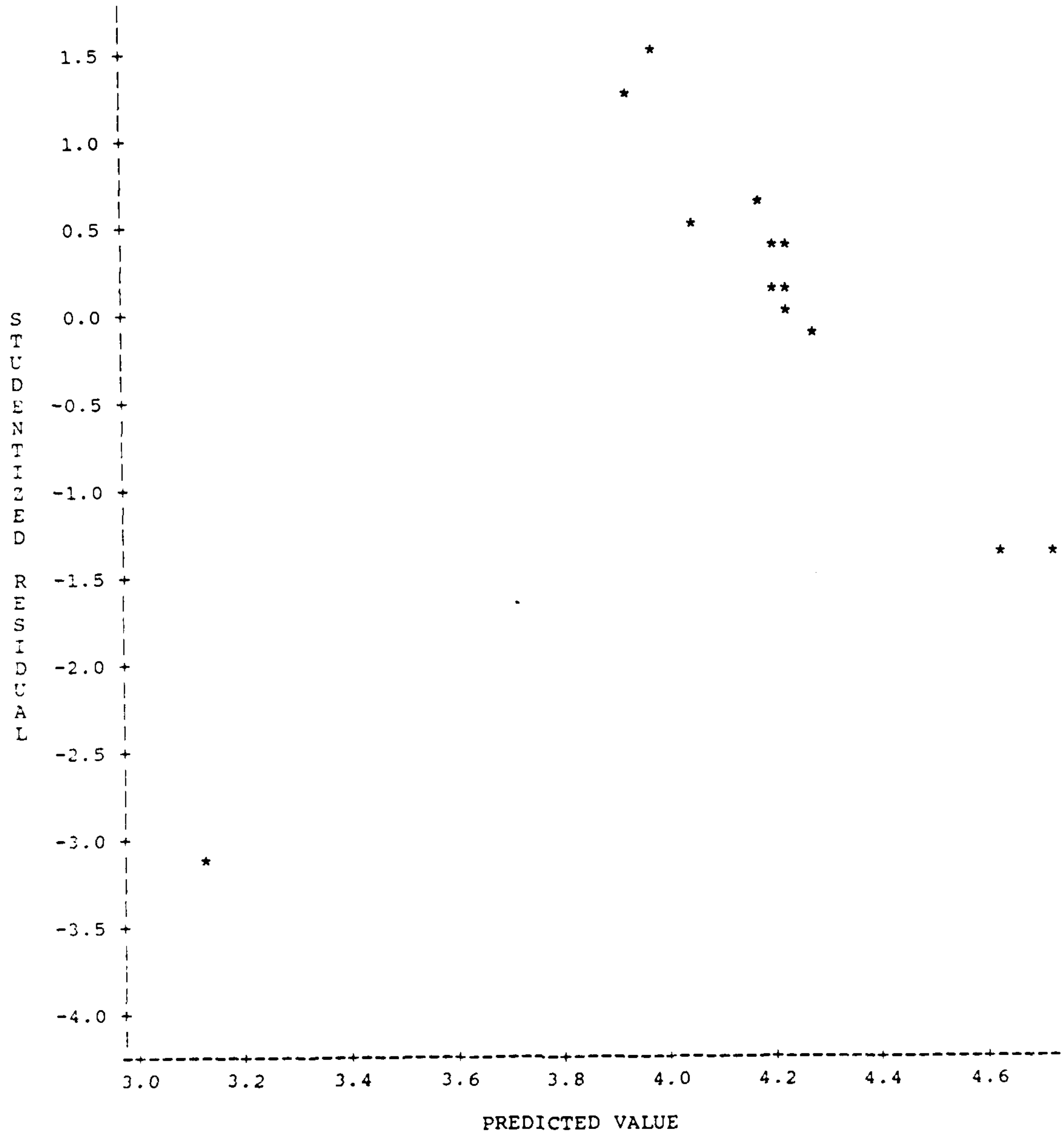
```
                  STD ERR   STUDENT                         COOK'S
OBS  RESIDUAL    RESIDUAL   RESIDUAL   -2 -1  0  1  2          D

  1  -.198674     0.1424    -1.3955    |    **|     |      0.247
  2  -.211227     0.1477    -1.4301    |    **|     |      0.193
  3  .0922077     0.1541     0.5985    |      |*    |      0.021
  4  -.019558     0.1512    -.129362   |      |     |      0.001
  5    0.2339     0.1589     1.4719    |      |**   |      0.078
```

OBS	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
6	0.1850	0.1491	1.2405	| |** |	0.133
7	-.007799	0.1491	-.052307	| | |	0.000
8	.0478951	0.1480	0.3235	| | |	0.010
9	.0713662	0.1571	0.4542	| | |	0.009
10	.0280211	0.1605	0.1746	| | |	0.001
11	.0184182	0.1226	0.1502	| | |	0.006
12	.0544296	0.1580	0.3445	| | |	0.005
13	-.293959	.0952699	-3.0855	|******| |	6.611

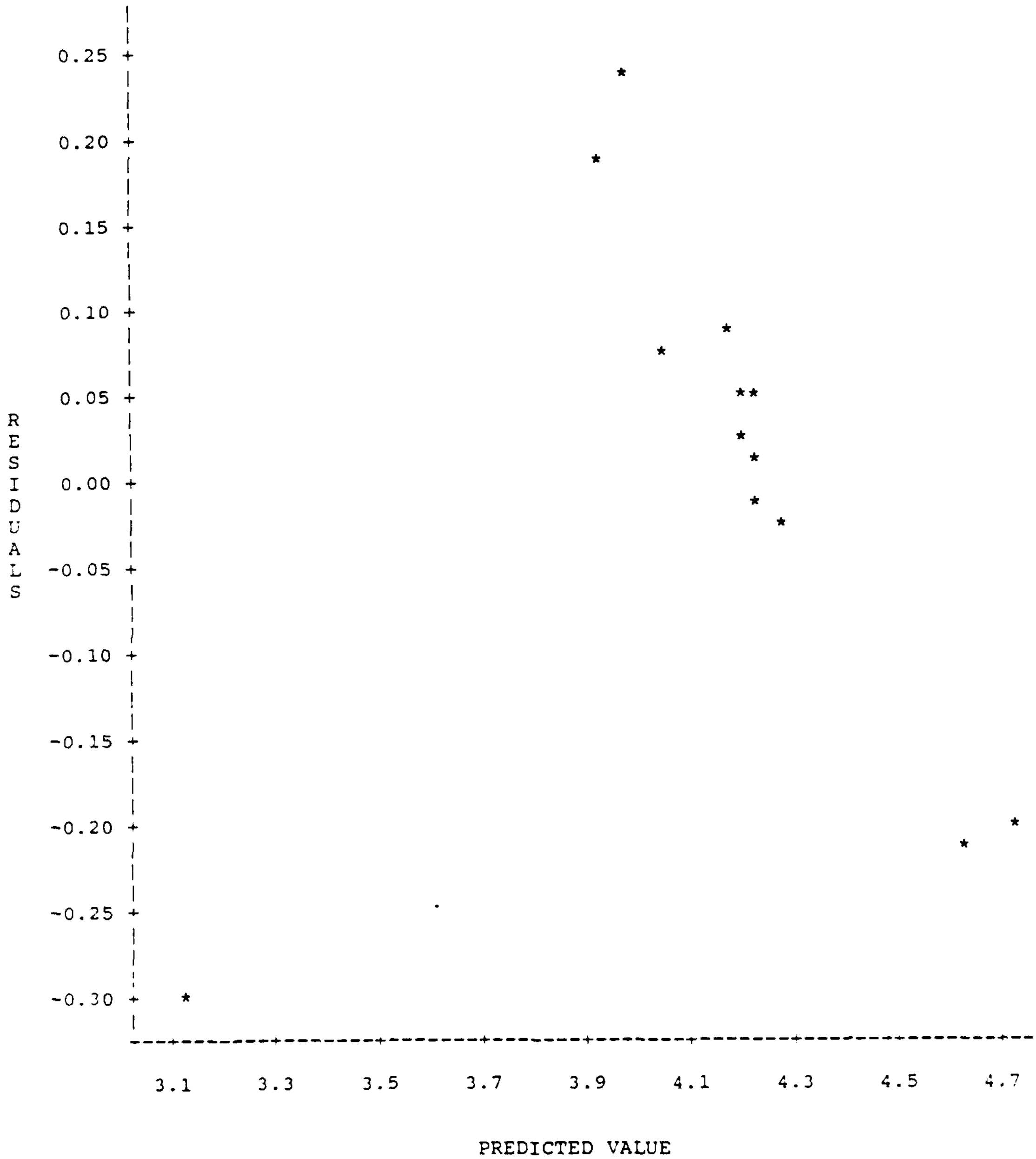
SUM OF RESIDUALS -2.05391E-15
SUM OF SQUARED RESIDUALS 0.2798454
PREDICTED RESID SS (PRESS) 1.120103

PLOT OF STRESS*PREDICT SYMBOL USED IS *



SAS 16:59 SATURDAY, APRIL 7, 1990 4

PLOT OF RESIDUAL*PREDICT SYMBOL USED IS *



UNIVARIATE

VARIABLE=RESIDUAL RESIDUALS

MOMENTS

N	13	SUM WGTS	13
MEAN	-1.580E-16	SUM	-2.054E-15
STD DEV	0.15271	VARIANCE	0.0233204
SKEWNESS	-0.611263	KURTOSIS	-0.0502208
USS	0.279845	CSS	0.279845
CV	-99999	STD MEAN	0.0423542
T:MEAN=0	-3.730E-15	PROB>|T|	1
SGN RANK	7.5	PROB>|S|	0.6247
NUM ^= 0	13		
W:NORMAL	0.924801	PROB<W	0.356

QUANTILES(DEF=4)

100% MAX	0.23389	99%	0.23389
75% Q3	0.081787	95%	0.23389
50% MED	0.0280211	90%	0.21433
25% Q1	-0.109116	10%	-0.260866
0% MIN	-0.293959	5%	-0.293959
		1%	-0.293959
RANGE	0.527849		
Q3-Q1	0.190903		
MODE	-0.293959		

EXTREMES

LOWEST	HIGHEST
-0.293959	0.0544296
-0.211227	0.0713662
-0.198674	0.0922077
-0.0195576	0.184989
-0.0077988	0.23389

DEP VARIABLE: GCI

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	3	3404.31033	1134.77011	96.548	0.0001
ERROR	9	105.78044184	11.75338243		
C TOTAL	12	3510.09077			

ROOT MSE	3.428321	R-SQUARE	0.9699
DEP MEAN	66.93846	ADJ R-SQ	0.9598
C.V.	5.121601		

PARAMETER ESTIMATES

VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB > |T|
INTERCEP	1	20.02306470	5.50041506	3.640	0.0054
DISTANCE	1	-0.00691152	0.001631327	-4.237	0.0022
WIND	1	2.88156766	0.36976686	7.793	0.0001
WINDCUB	1	-0.000650873	0.0003128239	-2.081	0.0672

OBS	ACTUAL	PREDICT VALUE	STD ERR PREDICT	LOWER95% MEAN	UPPER95% MEAN	LOWER95% PREDICT	UPPER95% PREDICT
1	92.2000	87.9911	2.7285	81.8188	94.1634	78.0793	97.9029
2	82.0000	85.2855	1.9669	80.8360	89.7350	76.3443	94.2267
3	70.9000	69.0840	1.4603	65.7804	72.3875	60.6542	77.5137
4	70.4000	72.8244	1.4770	69.4833	76.1656	64.3799	81.2690
5	66.5000	60.4996	1.3568	57.4302	63.5690	52.1589	68.8404
6	60.2000	57.4282	1.6143	53.7763	61.0802	48.8560	66.0005
7	68.0000	71.5420	1.6498	67.8099	75.2742	62.9353	80.1488
8	72.3000	71.7701	1.6865	67.9550	75.5852	63.1270	80.4132
9	61.3000	63.7895	1.3681	60.6946	66.8844	55.4393	72.1397
10	69.2000	70.8196	1.1277	68.2686	73.3706	62.6554	78.9839
11	69.1000	70.1303	2.3336	64.8512	75.4094	60.7486	79.5120
12	71.0000	70.6736	1.2422	67.8636	73.4836	62.4248	78.9224
13	17.1000	18.3620	3.3527	10.7775	25.9465	7.5143	29.2096

OBS	RESIDUAL	STD ERR RESIDUAL	STUDENT RESIDUAL	-2 -1 0 1 2	COOK'S D
1	4.2089	2.0758	2.0276	| |**** |	1.776
2	-3.2855	2.8080	-1.1701	| **| |	0.168
3	1.8160	3.1017	0.5855	| |* |	0.019
4	-2.4244	3.0939	-.783634	| *| |	0.035

```
                          STD ERR     STUDENT                              COOK'S
OBS      RESIDUAL        RESIDUAL    RESIDUAL     -2 -1  0  1  2              D

      5    6.0004          3.1484      1.9059     |      |***    |        0.169
      6    2.7718          3.0245      0.9164     |      |*      |        0.060
      7    -3.542          3.0053     -1.1786     |    **|       |        0.105
      8    0.5299          2.9848      0.1775     |      |       |        0.003
      9   -2.4895          3.1435     -.791953    |     *|       |        0.030
     10   -1.6196          3.2375     -.500259    |     *|       |        0.008
     11   -1.0303          2.5115     -0.41023    |      |       |        0.036
     12    0.3264          3.1954      0.1021     |      |       |        0.000
     13    -1.262          0.7159     -1.7627     |   ***|       |       17.037

SUM OF RESIDUALS             -2.75335E-14
SUM OF SQUARED RESIDUALS        105.7804
PREDICTED RESID SS (PRESS)          1108
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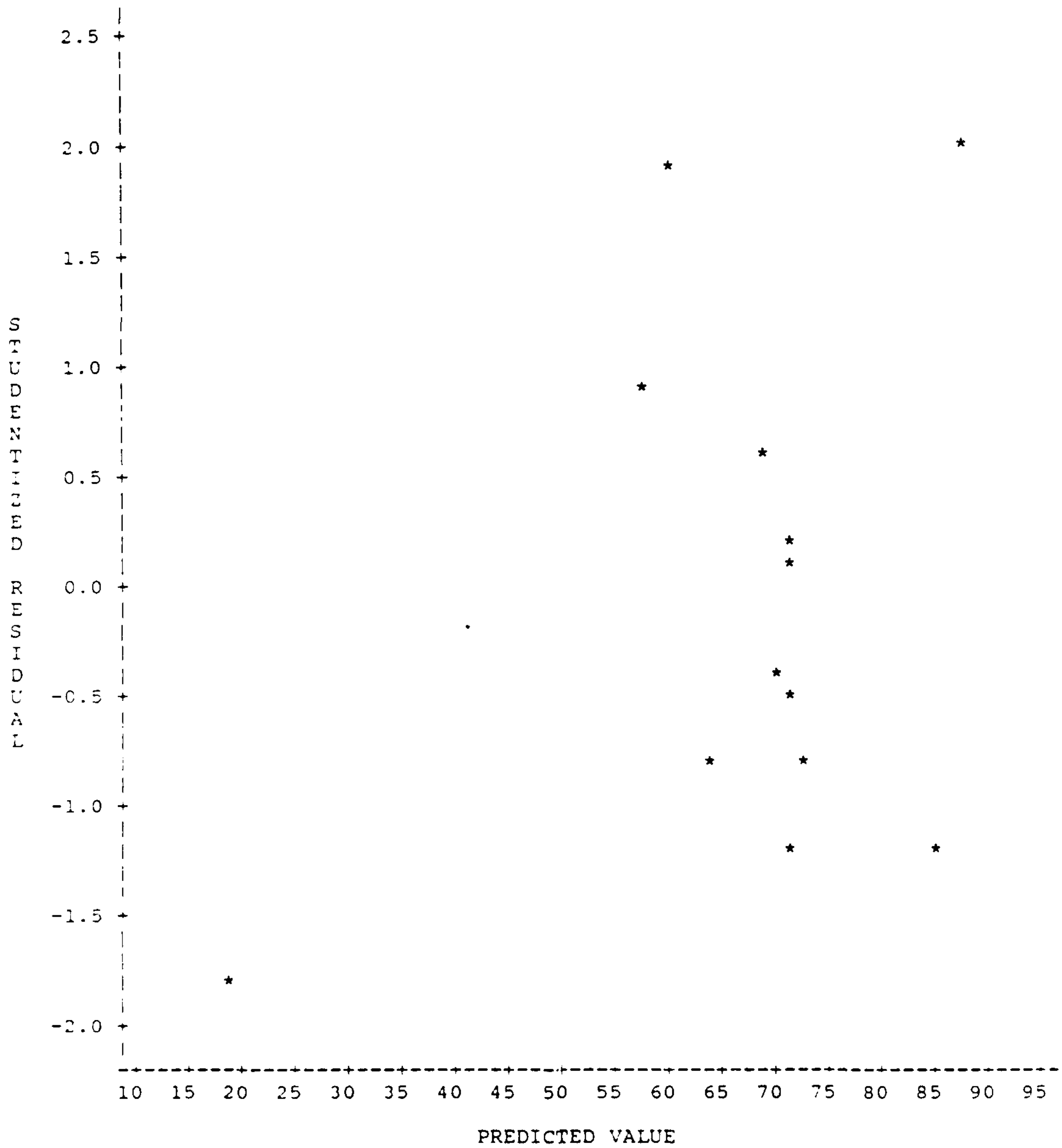
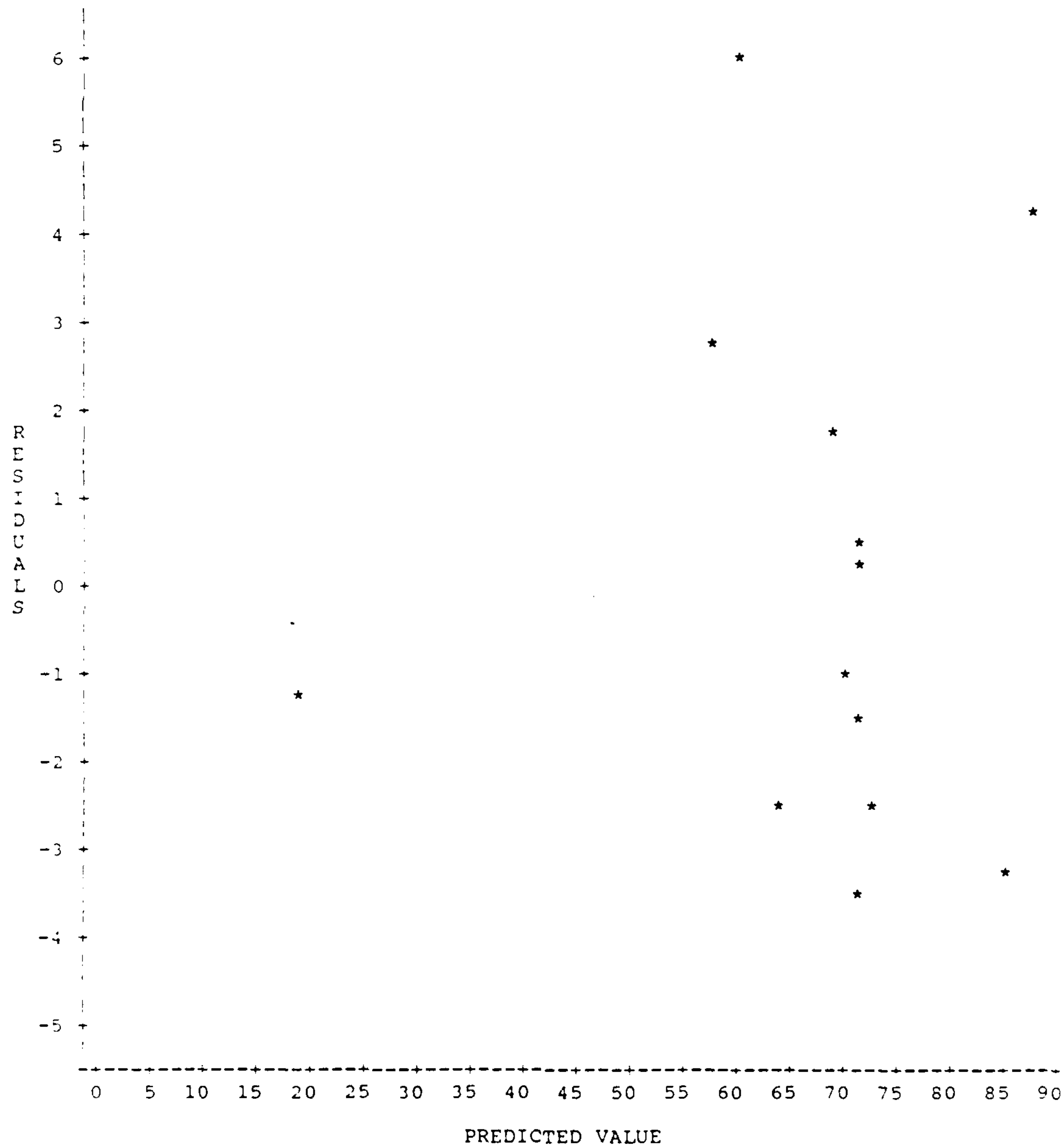
PLOT OF STRESS*PREDICT SYMBOL USED IS *



PLOT OF RESIDUAL*PREDICT SYMBOL USED IS *



UNIVARIATE

VARIABLE=RESIDUAL RESIDUALS

MOMENTS

N	13	SUM WGTS	13
MEAN	-2.118E-15	SUM	-2.753E-14
STD DEV	2.96901	VARIANCE	8.81504
SKEWNESS	0.756855	KURTOSIS	-0.311864
USS	105.78	CSS	105.78
CV	-99999	STD MEAN	0.823456
T:MEAN=0	-2.572E-15	PROB>|T|	1
SGN RANK	-2.5	PROB>|S|	0.888841
NUM ^= 0	13		
W:NORMAL	0.930358	PROB<W	0.395

QUANTILES(DEF=4)

100% MAX	6.00037	99%	6.00037
75% Q3	2.2939	95%	6.00037
50% MED	-1.0303	90%	5.28378
25% Q1	-2.457	10%	-3.4394
0% MIN	-3.542	5%	-3.542
		1%	-3.542
RANGE	9.54239		
Q3-Q1	4.75088		
MODE	-3.542		

EXTREMES

LOWEST	HIGHEST
-3.542	0.529896
-3.2855	1.81605
-2.4895	2.77175
-2.4244	4.20889
-1.6196	6.00037

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Francisco Javier Almagro Gonzales [redacted]raduated from the Air Force Academy in July 1971. Until coming to AFIT, he was assigned while a company and field grade officer as fighter pilot at several fighter units. As a result of his military and flight-related duties, he attended several schools (Jet Pilot at Talavera la Real, Spain; Close Air Support at Tablada, Spain; Flight Safety at University of Souther California, Norton AFB USA; and Field Grade Officers at Madrid, Spain). During those years, he was commissioned several times to participate in Combined Joint Operations in Spain, as well as at other NATO and non-NATO countries. He received his most rewarding and educational experiences while he was Commander, 462 Fighter Squadron, and later on, Commander, Maintenance Squadron, both at Gando AFB, Spain. He entered the Air Force Institute of Technology in May of 1989.

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